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COMPARATIVE PERFORMANCE ANALYSIS OF INTELLIGENT PID CONTROLLERS FOR A MECHATRONIC SYSTEM

BY

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Abstract. Applications of systems engineering in the automotive field have grown over the past two decades. This paper aims at a Model-Free Control (MFC) strategy for this type of application. It is a control method in the Data Driven Control (DDC) category that is suitable for systems with complex dynamics, uncertainties or dynamics that are difficult to model or with an unavailable model. Considering these reasons, MFC is an appropriate control method applicable to the complex dynamics of automotive systems. This paper presents a comparative analysis of two types of MFC controllers: intelligent proportional (iP) and intelligent proportional derivative (iPD) for a mechatronic system application. The system takes into account the longitudinal speed control of the vehicle. First, some authors results on the design of iP and iPD controllers are reviewed. Then, the intelligent controllers are tested in simulation considering the requirement to maintain the desired vehicle speed under different traffic conditions such as urban and extra-urban driving cycles. The control performances of the iP and iPD controllers are compared using different performance indices, with a classical PID controller added to the comparison.

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1. Introduction

One of the biggest objectives of automotive industry is to produce a fully autonomous vehicle with capabilities to run in any environment, without a driver. For this purpose, several intermediate steps are necessary, first of them being longitudinal and lateral control of the vehicle. These two types of control represent the basis on which functions like Adaptive Cruise Control, Lane Change Assist, Traffic Jam Assist, Emergency Brake Assist, Road Departure Protection can be added, but all of them are impossible to be realized without a good longitudinal and lateral control of the vehicle.

Longitudinal speed control of a vehicle represents one of the most common applications in automotive field, with lots of algorithms tried in applications known as Cruise Control. As the name suggests, the objective of this function is to control the longitudinal speed of the vehicle in cruising regime, which means constant high speed in extra-urban conditions. Cruise Control is a basic function included on lots of cars sold in the last two decades, while several control algorithms were used in researches. In (Ulsoy *et al.*, 2000), a PID controller was used for this type of application, in (Pauca *et al.*, 2019) the model predictive control was considered, while in (Marcano *et al.*, 2018) an advanced neuro fuzzy inference system was employed. Modern data driven algorithms were reported in (Polack *et al.*, 2017) and (Menhour *et al.*, 2018), demonstrating the superiority over the classical or advanced control method proposed before.

Model-Free Control (MFC) is a data driven strategy based on the input and output data of the plant, which was described in (Fliess and Join, 2013). The method is not dependent on the plant model, which makes it suitable for complex plants, with nonlinearities and uncertainties. Being a strategy independent of model, it can be used in noisy environment or in situations where a precise model is hard to be obtained or unavailable, which gives a definite advantage over the classical, model based, methods.

For this type of control strategy, the intelligent PID (iPID) controllers are used, which inherit the behaviour of the classical controllers, but add robustness and a better response on noisy signals. To tune this type of controllers, classical gain parameters for the proportional, integral and derivative components need to be elected and a scalar value chosen by the practitioner. The main problem is that it does not exist a clearly defined method how values of tuning gains are chosen and how an inexperienced practitioner can choose the mentioned scalar. Some methods for tuning are defined by combining MFC with other control strategies. Model-Free Control – Virtual Reference Feedback Tuning (MFC-VRFT) was applied in (Roman *et al.*, 2016), where the VRFT control method was used to identify in an automatic way the parameters for the PID intelligent controller. The mixed strategy MFC-VRFT needs a rewrite of command equations of iPID controller in a manner which matches the vector control form from VRFT. To obtain the values of the iPID controller parameters, it is necessary to do an identification of plant based on the input and output data, followed by the building of a virtual reference signal which leads the system to obtain the output data. Using the filtered command and error signals, the control vector can be obtained, which, in this case, will contain the parameters that tune the intelligent controller. Another method is the mix between MFC and Sliding Mode Control from (Wang *et al.*, 2015; Precup *et al.*, 2017), which uses the Sliding Mode to minimize the effect of the control error. The mixed strategy adds to the MFC control law an augmented command signal. Using this approach, the convergence and the stability are ensured with the required parameters. Based on the way how this mixed strategy is designed, the gains of the intelligent controller are not necessary and only a good election of the sliding surface parameters is needed.

Being a method designed to control plants with complex dynamics or even with unavailable model, MFC was used in different domains like robotics in (Villagra and Balaguer, 2011), for a complete humanoid simulator. In the medical domain (Bara *et al.*, 2018), it was employed to treat an acute inflammation, while in (Xu *et al.*, 2013), it was utilized to control a hydraulic system. In the automotive domain, it was used in (Polack *et al.*, 2017) and (Menhour *et al.*, 2018) for cruising applications, in (Choi *et al.*, 2009) to control a vehicle in Stop-and-Go scenario, while in (Abouaissa *et al.*, 2012), MFC was applied for traffic decongestion on a freeway ramp which increases traffic flow speed.

In this paper, a comparative analysis of the performances for two iPID controllers used to control the longitudinal speed of a vehicle is presented. Firstly, a review of some authors' results regarding the iP and iPD controllers design from (Baciu and Lazar 2019; Baciu and Lazar, 2020) is given. To ensure a zero steady state control error, first the Jury test described in (Fadali and Visioli, 2013) is applied to the characteristic polynomial of the error equation in order to obtain stable roots. Thus, a domain is obtained in the tuning parameters plane which ensures the tracking property. Then, the tuning parameters of the intelligent controllers are found with an algorithm based on a pole placement approach. Finally, the values of the parameters are finely tuned within the domain determined based on Jury test in order to improve the performances. The intelligent proportional (iP) and intelligent proportional derivative (iPD) controllers are used in a cruise control application considering two simulation scenarios, for urban and extra-urban traffic. These highlight the behaviour and differences between the designed controllers in two different traffic types. The urban traffic includes quick modifications of the speed reference, while the extra-urban one has constant or rare changes of the longitudinal speed.

This paper is structured as follows: Section 2 presents a review of iPID controller design, Section 3 shows the complex model of a drivetrain system used to test the iPID performances, Section 4 consists in a case study regarding the MFC for longitudinal speed control applied on, which compares the iP and iPD controllers with the classical PID, in two different scenarios, while Section 5 presents the conclusions.

2. iPID controllers design: a review of some results

2.1. Model free control principle

The intelligent controllers have, as classical PID controllers, several gains for the proportional, integral and derivative parameters which need to be tuned. For the classical PID controllers, methods like Ziegler-Nichols, Cohen-Coon or pole placement present clearly defined algorithms for parameters tuning and the way for their adjustment. Regarding the iPID controllers, things are not so clearly defined, the easiest method of tuning being "trial and error", the obtained values being checked if are included into an interval of trust which keeps the roots of the control error equation into a stability domain.

In the following, a review of some authors results from (Baciu and Lazar, 2020; Baciu and Lazar, 2019) regarding iPD and iP controllers design will be presented. For both types of controllers, a domain for the tuning parameters is found, that assures the stability of the solutions of the control error equation. After that, a pole placement method is applied, through which the controller parameters are obtained. If the performances are not the best, the parameters can be changed later, within the domain provided by the Jury Test.

The distinctive element of the MFC method compared to other DDC-type algorithms is the ultralocal model, defined by (Fliess and Join, 2013). This is valid for a very short period of time, being dependent on the control and output signals of the system, as can be seen in:

$$y^{(\nu)}(t) = F(t) + \alpha u(t) \ , \tag{1}$$

where $y(t)$ represents the output of the system, $u(t)$ the input of the system, $F(t)$ is a continuous updated element which contains the unmodeled components of the plant, α is a parameter chosen by practitioner and ν is the order of the derivative of the output signal.

Also, from (Fliess and Join, 2013), the iPID general equation is:

$$u(t) = \frac{\tilde{y}^{(\nu)}(t) - \hat{F}(t) + K_p e(t) + K_i \int e(\tau) d\tau + K_d \dot{e}(t)}{\alpha} \ , \tag{2}$$

where $\tilde{y}(t)$ represents the reference signal of the control system, K_p, K_i, K_d represent the proportional, integral and derivative gains of the controller, while $e(t)=\tilde{y}(t)-y(t)$ is the control error and $\hat{F}(t)$ the estimation of the parameter $F(t)$.

Substituting (2) into (1) and considering the very small estimation error $\delta(t)=F(t)-\hat{F}(t)$ that can be neglected (Roman, 2017), the error control equation is obtained:

$$e^{(\nu+1)}(t) \ + \ K_d\ddot{e}(t)+K_p\dot{e}(t)+K_ie(t)=0 \, . \tag{3}$$

The tracking property (i.e. $\lim_{t\to\infty} e(t)=0$) is fulfilled if the roots of the characteristic polynomial of the error equation (3) are stable. Based on this assumption, the gains of the iPID controllers can be found (Fliess and Join, 2013).

Depending on the order of the derivative, ν , two classes of controllers can be distinguished. Those using a derivative component have $\nu=2$, while those without a derivative component have $\nu=1$.

2.2. Design of the discrete iP and iPD controllers

As mentioned before, the value of ν in the ultralocal model (1) can be chosen to be 1 or 2. For an iP-type law (Fliess and Join, 2013) suggest that the first order of the derivative component is enough. Therefore, the ultralocal model in discrete-time approach for an iP law is:

$$\hat{y}(k)=F(k)+\alpha u(k) \, , \tag{4}$$

where $\hat{y}(k)\approx(y(k+1)-y(k))/T_s$ represents the approximation of the first derivative of $y(t)$ using the forward Euler discretization, and T_s is the sampling period.

The discrete-time iP control law is obtained from Eq. (2), with $\nu=1$ and $K_i=K_d=0$, resulting in:

$$u(k)=\frac{\hat{\tilde{y}}(k)-\hat{F}(k)+K_pe(k)}{\alpha} \, , \tag{5}$$

where $\hat{\tilde{y}}(k)$ represents the approximation of the first order derivative of the reference signal using the forward Euler discretization.

The estimation of $F(k)$ is obtained using the ultralocal model, as:

$$\hat{F}(k) = \hat{\dot{y}}(k) - \alpha u(k-1). \tag{6}$$

Introducing (5) in (4), with $\delta(k) = F(k) - \hat{F}(k)$ representing the error estimation, having a very small value, usually seen as a random disturbance which is neglected as in (Roman, 2017), the control error equation results:

$$e(k+1) - (1 - K_p T_s)e(k) = 0. \tag{7}$$

From (7), a zero steady-state control error can be obtained if the characteristic polynomial of the error equation:

$$P_{ce}(z) = z + K_p T_s - 1 \tag{8}$$

has a stable root inside the unit circle, i.e. $\left|1 - K_p T_s\right| < 1$ resulting in:

$$K_p \in \left(0, 2/T_s\right). \tag{9}$$

The discrete iPD control law can be obtained using the ultralocal model with $\nu = 2$. Therefore, Eq. (1), in the discrete approach becomes:

$$\hat{\ddot{y}}(k) = F(k) + \alpha u(k), \tag{10}$$

where the second derivative of the output signal is computed using the Euler approximation $\hat{\ddot{y}}(k) \approx (y(k) - 2y(k-1) + y(k-2))/T_s^2$.

The discrete form of the control law (2) for the iPD controller has the form (Baciu and Lazar, 2020):

$$u(k) = \frac{\hat{\ddot{y}}^*(k) - \hat{F}(k) + K_p e(k) + K_d \hat{\dot{e}}(k)}{\alpha}, \tag{11}$$

where the derivative of the control error is approximated by $\hat{\dot{e}}(k) \approx \left(e(k) - e(k-1)\right)/T_s$.

The control error equation is obtained combining (10) and (11), considering $\delta(k) \approx 0$ and the Euler's forward approximation of $\hat{\dot{y}}(k)$, $\hat{\ddot{y}}(k)$ and $\hat{\dot{e}}(k)$:

$$e(k+2) + (K_d T_s - 2)e(k+1) + (1 + K_p T_s + K_p T_s^2)e(k) = 0. \tag{12}$$

From (12) the characteristic polynomial of the control error equation is found as:

$$P_c(z) = z^2 + (T_s K_d - 2)z + 1 + T_s^2 K_p - T_s K_d . \qquad (13)$$

In order to satisfy the discrete-time tracking property, i.e. $\lim_{k\to\infty} e(k) = 0$, the roots of the characteristic polynomial (13) must be stable. To find the roots stability domain where K_p and K_d can take values, the Jury test from (Fadali and Visioli, 2013) is applied. Based on the Jury test, the following conditions need to be fulfilled to have the roots of the characteristic polynomial (13) inside the unit circle:

$$\begin{aligned} &P_c(1) > 0 \Rightarrow T_s^2 K_p > 0 \Rightarrow K_p > 0, \\ &(-1)^2 P_c(-1) > 0 \Rightarrow 4 - 2T_s K_d + T_s^2 K_p > 0, \\ &\left|1 + T_s^2 K_p - T_s K_d\right| < 1 \Rightarrow \begin{cases} T_s^2 K_p - T_s K_d < 0, \\ 2 + T_s^2 K_p - T_s K_d > 0. \end{cases} \end{aligned} \qquad (14)$$

As can be seen from (14), an important parameter is the sampling period, which has a direct impact in the resulting domain. As an example, the domain for a sample period of $T_s = 0.4$ sec is presented in Fig. 1.

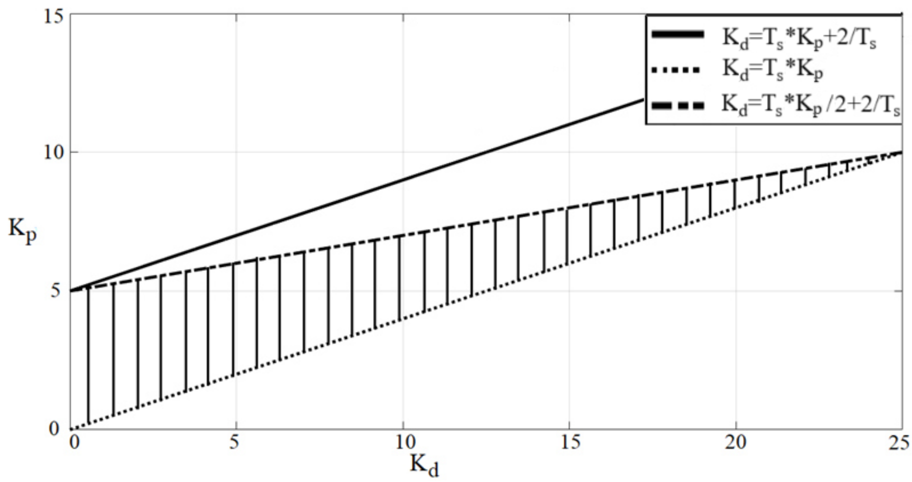

Fig. 1 – Roots stability domain in the tuning parameters plane for T_s=0.4 s.

In order to obtain a zero steady-state error, the domains (9) and (14) in the parameter plane where the gains of the iP and iPD controllers can take values are determined. Control error dynamics can be imposed by finding tuning parameters within the determined domains that satisfy a certain performance, typically settling time and overshoot. A method of designing tuning parameters can be the pole placement.

Thus, for iP controller, imposing a settling time t_{st}, the desired characteristic polynomial is obtained:

$$P_{ced}(z) = z - e^{-\frac{T_s}{t_{st}/3}}. \tag{15}$$

The equality of the polynomials (8) and (15) gives the iP gain:

$$K_p = \frac{1}{T_s}\left(1 - e^{-\frac{T_s}{t_{st}/3}}\right). \tag{16}$$

Similarly, for the iPD controller the desired second order characteristic polynomial can be found:

$$\begin{aligned} &P_{ced}(z) = z^2 + \alpha_1 z + \alpha_2, \\ &\alpha_1 = -2e^{-\zeta\omega_n T_s}(\cos\omega_n T_s\sqrt{1-\zeta^2}), \\ &\alpha_2 = e^{-2\zeta\omega_n T_s}, \end{aligned} \tag{17}$$

where the damping ratio ζ and the natural frequency ω_n are correlated with the overshoot and settling time performances. By identifying the polynomials (13) and (17), the relations for the iPD controller gains result as:

$$\begin{aligned} K_p &= \frac{\alpha_1 + \alpha_2 + 1}{T_s^2}, \\ K_d &= \frac{\alpha_1 + 2}{T_s}. \end{aligned} \tag{18}$$

The relations described in (16) and (18) represent a starting point for the design procedure of iP and iPD controllers, similar to classic PID. A fine tuning is necessary because the performances of the closed loop system are not dependent only on the placement of poles of the characteristic polynomial of the control error. Beside the gains K_p and K_d, an important parameter in the MFC law is α which is a parameter chosen by the practitioner. Furthermore, this parameter affects the result of the control loop, being in a relationship of relative proportionality with the gains of the iP and iPD controllers. Therefore, a small variation of α requires an adjustment of the K_p and K_d. The sampling period T_s is also a parameter which influences the gains, so it needs to be chosen according with the dynamics of the system.

So, the iP and iPD controller parameters require to be adjusted after a pole placement design to improve the performances of the closed loop system, but these values need to be inside of a bounded domain where the roots of the polynomial of the control error are stable.

3. Drivetrain system

The comparative case study of this paper analyses the MFC law for a complex mechatronic system representing the drivetrain of a vehicle from the engine throttle to the wheels. The subsystems used in such a description are some complex ones, based on non-linear mathematical equations. This is the reason why a control-oriented model of the whole system is difficult to be found with enough accuracy to be used with the classical model-based control strategies.

The drivetrain system model developed by Mathworks (https://www.mathworks.com), is used with the specific subsystems, depicted in Fig. 2, in MATLAB/Simulink environment. The system is a complex one, containing numerous interdependencies between the component blocks. The subsystems themselves have a level of complexity which is described below.

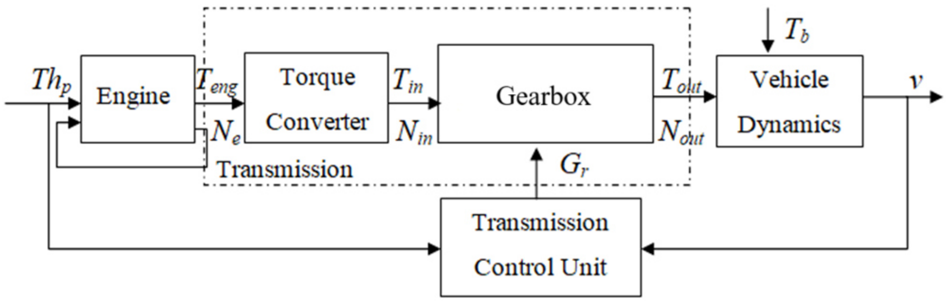

Fig. 2 – Mechatronic system structure.

The engine block is responsible for generating the combustion torque, T_{eng}. Later, after the drive chain processing, this is translated in wheel speed. The engine has a nonlinear component introduced by the map of the engine $f_1(Th_p, N_e)$ dependent on the throttle position Th_p and the angular speed of the engine N_e. The external load introduced by the impeller's torque T_i is also taken into account and, based on Newton's second law, the engine speed dynamics equation is:

$$J_{ei}\dot{N}_e = T_{eng} - T_i, \tag{19}$$

where J_{ei} represents the mass moment of inertia of the engine and the impeller.

The speed and torque from the engine are used inside the transmission component, which has two nonlinear subsystems: the torque converter and the gearbox. The torque converter uses two nonlinear maps, one for K-factor by the function $f_2(N_{in} / N_e)$ and the other offering the torque ratio R_{TQ} as the function $f_3(N_{in} / N_e)$, both functions being dependent on the speed ratio N_{in} / N_e. The gearbox behavior is described by a table dependent on the gear ratio G_R, while the transmission ratio i_t is used to obtain the transmission output torque $T_{out} = i_t T_{in}$. The resulted transmission speed is $N_{out} = N_{in} / i_t$, where N_{in} represents the transmission input speed. The transmission control unit implements the gear selection for the transmission. Beside these, the nonlinearities are amplified by the mathematical operations between the resulted signals as multiplication, squaring or dividing, which are used to obtain the torque of the impeller and the turbine.

The vehicle dynamics block represents the component of the system which offers the output of the system, the longitudinal speed of the vehicle. It includes the inertia, the final drive and the load of the vehicle, which are varying in a dynamic way and are described based on the Newton's second law of motion:

$$J_v \dot{N}_w = i_f (T_{out} - T_{load}), \tag{20}$$

where J_v represents the inertia of the vehicle, N_w the wheel speed, i_f the final drive ratio and T_{load} is the torque load. Considering the wheel radius r_w, the vehicle longitudinal speed is $v = r_w N_w$.

For the torque load definition, the brake torque and the road load are included, the equation which describes it being:

$$T_{load} = sign(v)\left(R_{load0} + R_{load2}v^2 + T_b\right), \tag{21}$$

where R_{load0} and R_{load2} represent the friction and aerodynamic drag coefficients, while T_b is the brake torque.

4. Comparative performance analysis of iPD and iP controllers vs PID

In the comparative case study, three control strategies are considered to control the vehicle longitudinal speed of the mechatronic system described in Section 3, in two different scenarios. The intelligent controllers, iP and iPD, are designed with the methods presented in Section 2.2, while a PID controller is designed using the pole placement method from (Astrom and Murray, 2008). Because the presented plant model is complex, an identification procedure was necessary for the PID tuning approach. For this, an ARX model was obtained with System Identification Toolbox from MATLAB, using a Pseudo-Random Binary Sequence as the input signal, for the plant resulting the transfer function: $G_p\left(z^{-1}\right)=0.008787z^{-2}/\left(1-1.681z^{-1}+0.6856z^{-2}\right)$. Based on the transfer function, the PID controller was tuned, using the pole placement method by imposing the performances: settling time 25 seconds and overshoot 0.15%.

The simulation scenarios are based on the European Driving Cycle (EDC), being about the urban scenario of EDC which simulates 200 seconds of urban driving. The second scenario is for the extra-urban environment which simulates 400 seconds of driving, using high speeds. On each scenario, signals with various forms on disturbances input, for road slope and wind speed were applied.

The results are obtained in simulation, using MATLAB/Simulink and the model from (https://www.mathworks.com). The model has two different inputs signals representing the throttle and brake inputs, similar with a real vehicle with automatic transmission. Using this approach, a control method is required for the brake signal and a proportional controller is used in this situation. The values of the signal applied on the brake input are around 400 Nm for normal braking situations and 700 Nm for an emergency brake situation. The value of the tuning parameter of the proportional controller is obtained using the "trial-and-error" method.

4.1. The urban scenario

The EDC cycle is used by all automobile manufacturers to report the CO_2 emissions and fuel consumption for the European continent. The first scenario is the urban component of EDC, with 200 seconds of urban driving which means short accelerations, a small period of constant speed followed by a break to zero, with a speed limited to 50 km/h. The results of the comparison between the iPD, iP and PID controllers used in the closed loop for the urban scenario are presented in Fig. 3.

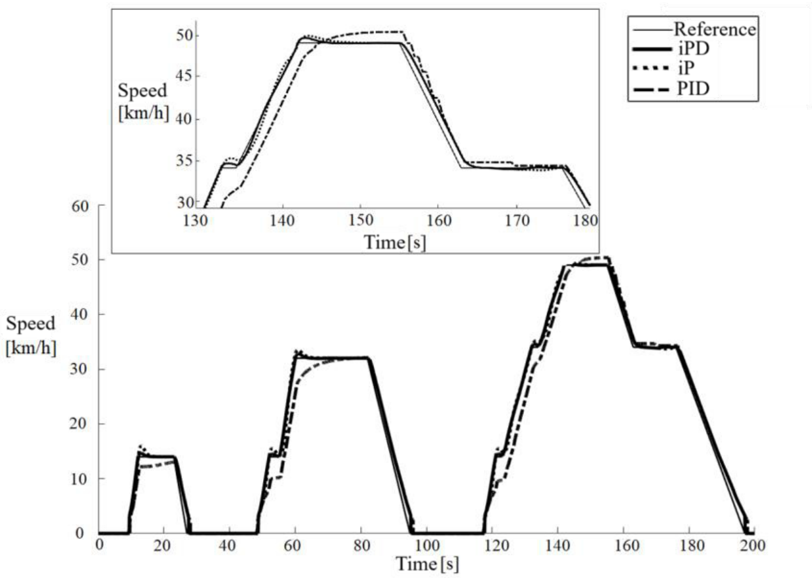

Fig. 3 – Vehicle longitudinal speed for urban scenario.

As Fig. 3 shows, the intelligent PID controllers have a better responsiveness at sudden changes of speed, which is completely missed in the PID case. The classical controller has a delayed response, which on the last sector of acceleration introduces overshoot, an undesirable effect in this type of situation. So, to conclude, in urban scenario the iPID controllers have a better response in terms of the settling time and the overshoot in comparison with the classical PID. As the zoom presented in Fig. 3 shows, the iPD law has a faster response than iP, provided by the derivative component.

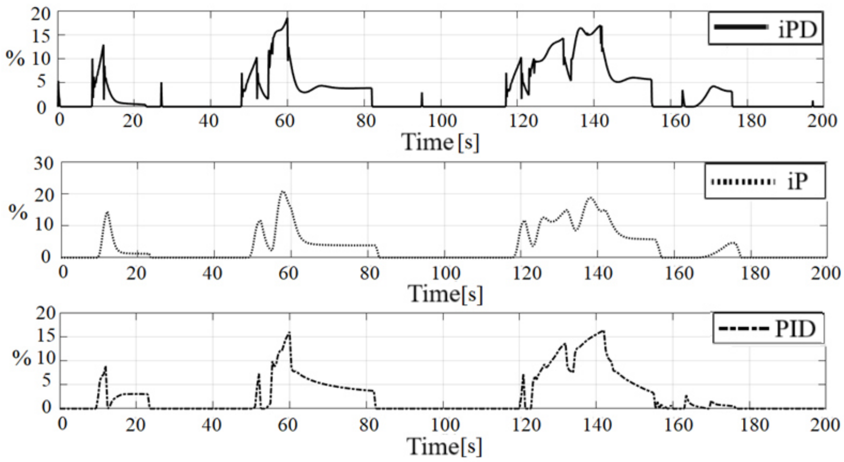

Fig. 4 – Throttle position (percent) variation for urban scenario.

The control signals representing the throttle position (percent) for all three controllers used in the urban scenario are presented in Fig. 4. In the iPD case, it is visible a very responsive response with the most changes of the throttle position. In the case of iPD, rapid changes in the percentage at which the throttle is pressed are visible, consistent with the requirements imposed by the speed reference signal. For all variations of the reference signal, prompt changes in throttle angle can be observed, which provide superior dynamic response when such a controller is used. On the other hand, the iP law provides fewer variations of the control signal, but with a good response of the output signal.

To evaluate the results obtained with the controllers, the following performance indices was used, based on the average and variance of the control error:

$$J_{\varepsilon a} = \frac{1}{N}\sum_{k=1}^{N}\left|e\left(k\right)\right|, \tag{22}$$

$$J_{\varepsilon v} = \frac{1}{N}\sum_{k=1}^{N}\left[e(k) - \overline{e}\right]^2, \tag{23}$$

where N represents the total number of samples in the simulation test and $\overline{e}$ the average of the absolute control error.

The results of the evaluation in urban scenario are presented in Table 1.

Table 1
Urban scenario performance index

	iPD	iP	PID
$J_{\varepsilon a}$	0.54	0.70	1.60
$J_{\varepsilon v}$	0.71	0.81	2.90

From Table 1, it can be seen that the Model-Free Control algorithms show much smaller errors than the implemented PID law. In addition to the absolute mean value, the variance also shows the advantages of iPD and iP controllers over PID. Strictly analyzing the MFC laws, the advantages of the derivative component of iPD are highlighted by this analysis, both from the point of view of absolute error and from the point of view of variance.

4.2. The extra-urban scenario

The extra-urban scenario consists in several acceleration phases followed by a period of constant speed. The period of simulation is 400 seconds while the limit of speed is 120 km/h, being a proper scenario for the Cruise Control function. As Fig. 5 shows, all the control laws used have succeeded to follow the reference signal with small errors. As the zoom shows, only the PID controller has a response slightly delayed and with an overshoot, while the intelligent controllers follow the reference with high accuracy.

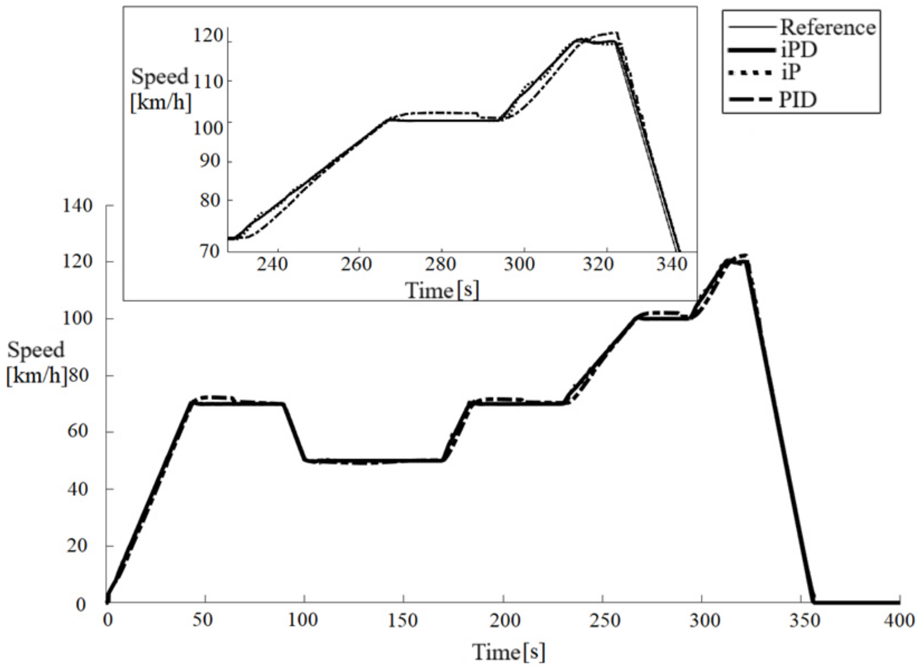

Fig. 5 – Vehicle longitudinal speed for extra-urban scenario

The variation of the control signals for the extra-urban scenario is shown in Fig. 6. The pattern from the urban scenario is maintained, with an iPD controller very responsive, which modifies the throttle position as soon as a disturbance appears or the reference signal changes. Being a scenario that does not involve as many variations as the previous one, the iP control signal is quite similar with several small differences, but the behavior is the desired one. On the other hand, the control signal of the PID controller has great differences in comparison with the intelligent PID controllers. It varies more slowly than in the case of the intelligent controllers, which is a reason for an increased settling time. The overshoot seen in the case of PID comes from a high level of throttle opening. These shortcomings are caused by the fact that this type of control works properly only when an accurate model is available.

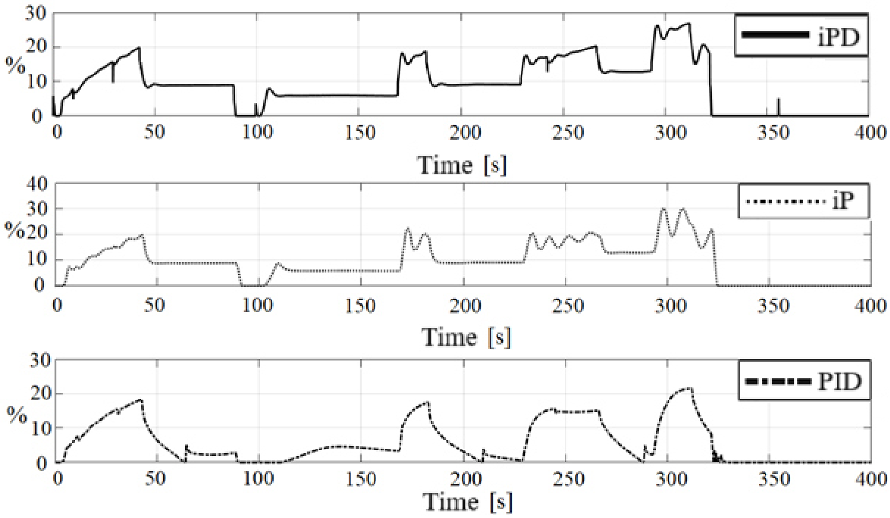

Fig. 6 – Throttle position variation for extra-urban scenario.

The extra-urban scenario is evaluated using the performance indices (22) and (23). The results are presented in Table 2.

Table 2
Extra-urban scenario performance index

	iPD	iP	PID
$J_{\varepsilon a}$	0.33	0.44	1.30
$J_{\varepsilon v}$	0.63	0.68	1.28

The conclusions expressed following the analysis of Fig. 5 are confirmed through Table 2. The average errors of the Model-Free laws are lower than those of the PID, a similar conclusion can be drawn regarding the variance. Another aspect highlighted from the analysis of the two intelligent controllers, is that for such a scenario, which does not foresee sudden and repeated speed changes, an iP law offers a relatively similar response to the iPD one, being more suitable, due to its simplicity.

5. Conclusions

This paper proposes the iP and iPD control algorithms for a mechatronic system, designed to control the longitudinal speed of a vehicle. A review of some authors results regarding the iP and iPD controllers design is presented. The control laws were tested in simulation, using two different scenarios from EDC cycles. The scenarios involve maintaining the desired longitudinal speed of the vehicle in urban and extra-urban conditions, the first being an idea of the authors, while the second is a classical cruising scenario. Based on these scenarios, the performances of the controllers were evaluated. The simulations revealed that the iPID controllers are superior, in terms of performances, in comparison with the classical controller. This superiority is exacerbated in situations when the speed varies suddenly, especially on high-acceleration levels, where the classical PID controller has big delay and overshoot, a fact that was not found in the case of intelligent controllers. On the high acceleration zones, the iP controller has a little bit more overshoot than the iPD controller, being devoid of missing the derivative component of error.

The numerical analysis introduced to evaluate the control strategies using the performance indices confirms the aspects regarding the performances. In both scenarios, the average of the absolute control error is smaller for the iPD controller than the iP, while the PID controller has higher values. The behaviour is similar when the variance of the error is the analysis subject.

Following the analysis performed, it turned out that the iPID controllers have a better behaviour in terms of performance and accuracy in comparison with the classical PID controller for the complex mechatronic system, with an advantage of the law that benefits from a derivative component compared to the iP algorithm.

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ANALIZA COMPARATIVĂ A PERFORMANȚEOR REGULATOARELOR PID INTELIGENTE PENTRU UN SISTEM MECATRONIC

(Rezumat)

Aplicațiile din ingineria sistemelor din domeniul automotive au crescut în ultimele două decade. Această lucrare propune o strategie Model-Free Control (MFC) pentru acest tip de aplicație. Este o metodă de control de tip Data Driven care este destinată pentru sisteme cu o dinamică complexă, incertitudini sau dinamici care sunt dificil de modelat sau pentru situații în care modelele nu sunt disponibile. Luând în considerație aceste motive, MFC este o metodă de control aplicabilă pentru sisteme complexe din domeniul automotive.

Lucrarea prezintă o analiză comparativă a două tipuri de regulatoare MFC, cel Proporțional inteligent (iP) și cel Proporțional Derivativ inteligent (iPD) pentru un sistem mecatronic complex. Sistemul considerat controlează viteza longitudinală a unui vehicul. Regulatoarele inteligente au fost testate în simulare luând în considerare cerința de a menține o viteză definită a vehiculului în condiții variate, precum ciclurile de conducere urban și extra-urban. Performanțele regulatoarelor iP și iPD au fost analizate comparativ folosind diferiți indici de performanță, în comparație fiind adăugat și un regulator clasic PID.